OFFICE OF RESEARCH AND DEVELOPMENT
GLOBAL CHANGE
RESEARCH STRATEGY

EXTERNAL REVIEW DRAFT

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1. INTRODUCTION

> *"The balance of evidence suggests a discernible human influence on global climate." IPCC, 1995*

Human-induced factors are now formally recognized by the international community to have a significant influence on climate change and are likely to lead to unprecedented rates of warming over the next century. The Intergovernmental Panel on Climate Change (IPCC) summarized this conclusion in the 1995 Assessment when it stated "The balance of evidence suggests a discernible human influence on global climate." The impacts of this climate change are uncertain, and the Environmental Protection Agency (EPA), along with other federal agencies and the international community, have a substantial program underway to determine the degree of vulnerability of natural ecological systems to climate change, assess the potential human health effects, and evaluate socioeconomic consequences of the anticipated climate changes.

Concurrent with the effort to assess impacts, the international community has initiated formal discussions to consider how to respond to the monumental challenge of reducing anthropogenic emissions of greenhouse gases (GHGs) and adapt to the warming that is expected to occur regardless of actions taken to reduce emissions. Representatives from 150 countries have come together under the auspices of the UN Framework Convention on Climate Change to negotiate and eventually recommend actions to curb increases in atmospheric GHG concentrations. During the most recent meeting of the Conference of Parties in July 1996, the US laid out a set of principles to guide the next round of international negotiations expected to be completed by the Fall of 1997. The most significant US proposal was for the inclusion of binding GHG reduction targets that can be achieved and verified in the near-term. Although the specific approach that will be used to implement this new policy position is unclear, the international community has decided it cannot wait for all the information on the effects of climate change before some concrete action is taken.

Based on these recent developments, guidance in the Office of Research and Development's (ORD) strategic plan, and the priorities specified in the FY 1997 Our Changing Planet by the US Global Change Research Program (USGCRP), ORD will strategically invest in global change research. The research conducted will provide policymakers with information on potential ecological and human health consequences of climate change and technical data needed to evaluate alternative GHG emission reduction and adaptation approaches. Significant targeted investments in research now will place the US in a leadership role and provide information and options needed to understand and address climate change-induced stress in the context of other stressors. ORD has embraced the need for such leadership by establishing as one of its primary strategic goals "to provide leadership and encourage others to participate in identifying emerging environmental issues, characterizing the risks associated with these issues and developing ways of preventing or reducing these risks." With this goal in mind, ORD identified global change research as an area of high importance that will continue to be a major part of ORD's research program.

2. RESEARCH PLANNING FRAMEWORK

Two steps were initially undertaken as part of the strategic process to develop this plan: (1) assessment of current knowledge and (2) a review of current Federal priorities. The results of these two steps are described in abbreviated fashion in this section; the IPCC and USGCRP documents discussed in the Introduction elaborate on the knowledge base and gaps affecting EPA's strategic research planning for global change.

Assessment of Current Knowledge

Intergovernmental Panel on Climate Change

In 1990 and 1995, the multinational IPCC summarized the state of the knowledge and the major uncertainties in the science of global change. Several hundred scientists contributed to the assessments contained in the IPCC reports, including several from EPA ORD and Program Offices. Evidence from these documents and other recent sources indicate that the concentration of some climate change drivers such as CO_2 and methane, the two most important greenhouse gases, are increasing exponentially in Earth's atmosphere as a result of human activities (e.g., fossil fuel combustion and extensive deforestation). Global mean surface air temperature has already increased between 0.3 and 0.6°C since the late 19th century, and projections from General Circulation Models (GCMs) indicate that the global average temperature will further increase 2°C by 2100, with a range of projections of 1°C to 3.5°C.

Effects of climate change that are likely precursors of events to come are beginning to be seen around the globe. Recent years have been among the warmest since 1860 (in the period of instrumental record) despite the cooling effect of the 1991 Mt. Pinatubo volcanic eruption. Night-time temperatures over land have generally increased more than daytime temperatures. Regional changes are also evident. For example, the recent warming has been greatest over the mid-latitude continents in winter and spring, with a few areas of cooling such as the North Atlantic ocean. Precipitation has increased over land in high latitudes of the Northern Hemisphere, especially during the cold season. Global sea level has risen by between 10 and 25 cm over the past 100 years and much of the rise may be related to the increase in global mean temperature. There are inadequate data to determine whether consistent global changes in climate variability or weather extremes have occurred over the 20th Century. On regional scales there is clear evidence of changes in some extremes and climate variability indicators (e.g., fewer frosts in several widespread areas; an increase in the proportion of rainfall from extreme events over the contiguous states of the US). Some of these changes have been toward greater variability; some have been toward lower variability.

GCMs project greater global precipitation, but perhaps in insufficient amounts to compensate for greater evaporation caused by warmer temperatures in some regions. The frequency, distribution and intensity of climate and hydrological patterns will very likely change, significantly modifying natural ecosystems and traditional socio-economic patterns in affected areas. While prediction of specific ecological responses is very difficult and the subject of much ongoing research, it is likely that some systems will respond more quickly to climate change than others, that they will be affected to widely varying degrees, and that some changes will be adapted to much more easily than others.

Efforts to manage the adverse effects identified above will require both reductions of GHGs from a variety of sources across many economic sectors and the implementation of adaptation approaches to compensate for the changes that are likely to occur. Sources of GHG emissions include utility power generation, combustion, vehicles, waste disposal, petroleum production, coal mines, substitutes for ozone depleting substances, ruminants, and agricultural operations. Currently available approaches to reduce emissions from these sources include CO_2 reduction through improved energy efficiency, improved farm management, nuclear power, hydropower, and fuel switching. While implementation of some of these options is feasible, others are either prohibitively expensive, not widely accepted by the public (e.g. nuclear power), or will not be adequate to achieve the reductions needed to completely curb future warming. New solutions for many of these sources, particularly those in the energy supply and transporta-tion sectors, must be pursued over the next decade to ensure the US and other nations have viable and affordable options to reduce emissions. Models to compare the range of mitigation approaches available have been used by the IPCC and others to provide policymakers with unbiased information on the effectiveness of alternative emission reduction options for key economic sectors. These comparisons have been produced using available information on emissions and the relative costs and performance of technologies. Studies that will upgrade or refine the input data used in these models have been identified by the IPCC as a high priority.

Adaptation strategies will also be a critical component of the overall approach to managing global change risks because some additional increase in global average temperature is expected to occur. The IPCC defines adaptability as "...the degree to which adjustments are possible in practices, processes, or structures of systems to projected or actual changes of climate. Adaptation can be spontaneous or planned and can be carried out in response to or in anticipation of changes in conditions." While some options have been considered for agriculture and forestry, there has not been an integrated program to evaluate adaptation strategies for vulnerable aquatic and terrestrial ecosystems or to understand how global change will impact other environmental protection strategies. Adaptation options that can simultaneously respond to global change and other environmental stressors will be the most desirable. Future implementation of adaptation approaches will be closely tied to results produced by EPA and other researchers who are conducting studies to quantify potential implications of climate change.

Current Federal Priorities

U.S. Global Change Research Program

Earth's environment is constantly changing due to the complex interplay of both natural and human-related activities. As noted above, scientific knowledge is just now beginning to show that humans have come to play a powerful and expanding role as agents of environmental change. Thus, the current and future state of the global environment is inexorably linked to human activities. The US, through the USGCRP, along with other nations, supports the research needed to characterize and understand global environmental change and to provide answers to important questions about the Earth system such as how is it changing, and what are the implications of change for society, natural ecosystems, and resource systems on which society depends.

Established as a Presidential Initiative in the FY90 budget, the USGCRP has been responsible for directing Federally-supported scientific research to address key uncertainties about global change and the Earth system. The overall goals of this program are to: (1) observe and document changes in the Earth system; (2) understand what changes are occurring and why; (3) improve predictions of future global change; (4) analyze the environmental, socioeconomic, and health consequences of global change; and (5) support state-of-the-science assessments of global change issues. EPA has been an active participant in the USGCRP since its inception.

The USGCRP budget for FY97 is about $1.74 billion, with 10 agencies, including EPA, participating in the program. The programmatic contributions of the USGCRP agencies are coordinated and closely matched to agency missions and areas of expertise. In response to an on-going review of the US program by the National Research Council, the research has focused on priority issues in four areas of Earth system science that are of great scientific and practical importance. These Priority Science Issues are:

(1) Seasonal to Interannual Climate Variability, to obtain a predictive understanding to produce forecasts of short-term climate fluctuations and to apply these predictions to problems of social and economic importance in the US and abroad.

(2) Climate Change over Decades to Centuries, to understand, predict, assess, and prepare for changes in the climate and global environment that will result from the influences of anticipated changes in population, energy use, land cover, and other natural and human-induced factors.

(3) Changes in Ozone, UV Radiation, and Atmospheric Chemistry, to understand and characterize the chemical changes in the global atmosphere and their consequences for human and ecosystem health and well-being.

(4) Changes in Land Cover and in Terrestrial and Marine Ecosystems, to provide a stronger scientific basis for understanding, predicting, assessing, and responding to the causes and consequences of changes in terrestrial, aquatic and marine ecosystems resulting from human-induced and natural influences.

In addition, to provide the basis for continuing advancement in scientific understanding and to fulfill the U.S. commitment to international leadership in global change research, the USGCRP lists a number of Integrating Research Themes that support essential ongoing integrative and cooperative efforts:

(1) Observing and Monitoring Global Change, with the goal of ensuring the availability of a long-term, high-quality observational record of the state of the Earth system, its natural variability, and changes that are occurring over extended time scales.

(2) Global Change Data, Products, and Information Services, with the goal of providing all users ready and affordable access in useful forms to the full spectrum of global change data, products and information.

(3) *Earth System Science***,** with the goal of supporting the long-term, integrated, and exploratory research needed to gain a predictive understanding of the interactions among the physical, chemical, geological, ecological, and solar processes that determine the functioning of the Earth system and its trends and fluctuations on global and regional scales.

(4) *Human Contributions and Responses to Global Change***,** with the goal of identifying, understanding, and analyzing how human activities contribute to changes in natural systems, how the consequences of natural and human-induced change affect the health and well-being of humans and their institutions, and how humans could potentially respond to problems associated with environmental change.

(5) *International Research Cooperation***,** with the goal of supporting and assisting the program and its participating scientists and agencies in their interactions with related international research, observing, and assessment activities and in the full and open international sharing for data and research findings.

(6) *Global Change Education and Communication*, with the goal of increasing public awareness of the Earth system and how it is changing and to promote global change education.

The Relationship of ORD's Program and the USGCRP

With the exception of the first goal of the USGCRP, which is addressed by other research programs, ORD's Global Change Research Program is directly aligned with the following USGCRP goals and integrating themes:

- *USGCRP Goal 2: Climate Change over Decades to Centuries*, ORD conducts process-level research to improve understanding of the sources, sinks, and transformation of GHGs . ORD also conducts research on the integration of terrestrial GHG emissions in Earth system models and develops analytical tools and case studies that can be used by policymakers to evaluate the viability of emission reduction and adaptation approaches.

- *USGCRP Goal 3: Changes in Ozone, UV Radiation, and Atmospheric Chemistry*, EPA and ORD programs focus on development and deployment of a monitoring network, and provides leadership for the international assessments of the technical and economic feasibility of developing and deploying new technologies to protect the ozone layer. Supporting research on tropospheric ozone and ecosystem protection research, especially the Environmental Monitoring and Assessment Program (EMAP), also contributes to this area.

- *USGCRP Goal 4: Changes in Land Cover and in Terrestrial and Marine Ecosystems*, This research goal is one of two primary foci of the US EPA ORD research program. Research and monitoring conducted for Goals 2 and 3 contribute directly to this primary goal. For example, earlier research in Earth System Models is now used to project regional climate scenarios for vulnerability studies in the Mid-Atlantic, the Southeast, the

Pacific Northwest, and other regions of the US. These studies aim to address effects of climate change on freshwater, coastal, and terrestrial ecosystems. Supporting research in EMAP and Ecological Risk Assessment Methods also contributes to this area.

- *USGCRP Integrating Theme 4: Human Contributions and Responses to Global Change*, ORD plans to advance the capability of the US and the international community to compare alternative GHG emission reduction technologies and adaptation approaches, and to examine the implications of climate change on humans both through direct impacts (e.g., heat stress) and indirect impacts (e.g, disease vectors). Analyses conducted will help establish priorities for future research on adaptation and GHG reduction technologies and could be used by policymakers to understand the relative cost and performance of available technologies. EPA/ORD will build on the technology analyses contained in the IPCC assessment by filling gaps in knowledge which currently impede quantitative comparisons of some GHG emission reduction options. Case studies and assessments will also be performed to evaluate various adaptation options with an initial emphasis to determine how existing environmental protection strategies may need to be adjusted due to climate change.

Evolution of the EPA Research Program

In the early 1990's EPA's Global Change Program had the research components shown in Table 1. By mid 1994, with initial research results coming in, EPA's global change program managers re-evaluated their strategy. It was clear that EPA had strong in-house expertise in ecosystem science and could make a significant contribution by focusing a large component of the program on ecological vulnerabilities. Additionally, this was an area highlighted by the National Science and Technology Council's Committee on Environment and Natural Resources (CENR) for increasing emphasis. According to *Our Changing Planet, the FY95 Global Change Research Program*, "the FY 95 program proposed to enhance research to improve fundamental understanding of physiological and ecological responses of plants and animals to global change of climate, atmospheric gas concentrations, and increased UV-B radiation... New research will be initiated to evaluate the potential impacts of climate change at the regional level."

EPA Office	Program Title
ORD	Terrestrial Carbon Flux Tracking
ORD	Developing Predictive Models
ORD	Regional Vulnerabilities
ORD	Integrated Assessment Research
ORD	Stratospheric Ozone Depletion
OARM	Data Management, Access, and Integration
OPPE	Policy Assessment Research

Table 1. Previous Research Program Components

In order to select priority regions for research and assessment, a workshop with external reviewers was held in August, 1994. First, regions having some ecological similarity were identified. Examples include the Southeast, New England, and Great Basin. Then, criteria for assessing regional susceptibility to climate change were selected. These included ecosystem productivity, susceptibility to extreme events, national security (food and energy production), and water quality and quantity. Also considered were existing databases, ongoing research, and assessment efforts. The Southeast,

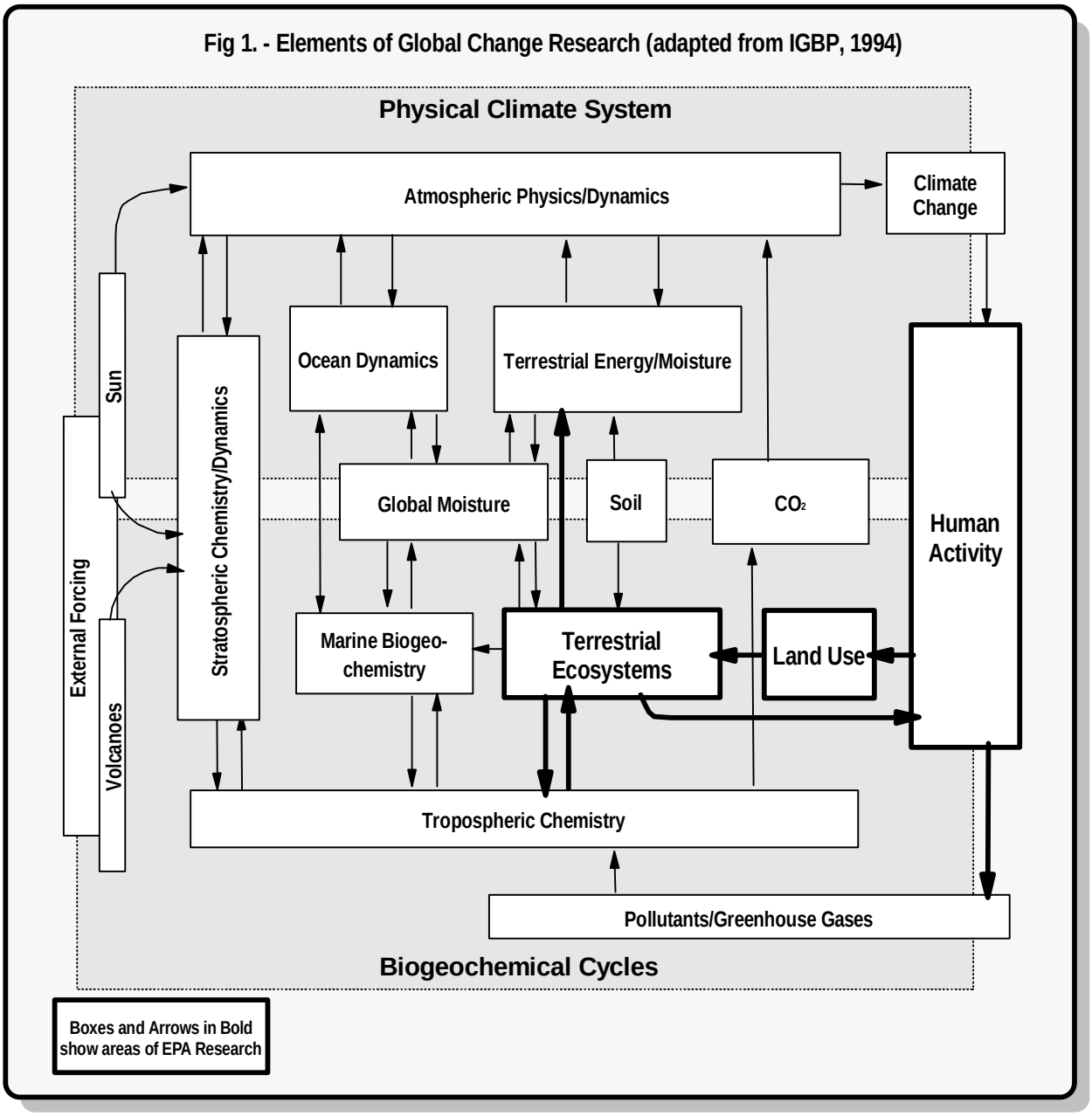
Mid-Atlantic, Great Plains, and Pacific Northwest emerged as high priority regions for assessing regional vulnerabilities to climate change.

EPA's program also included research to reduce uncertainties associated with domestic estimates of GHG emissions, particularly methane, and to investigate potential mitigation options. In the early 1990's, the emissions component of the program conducted studies to reduce the large uncertainties in the estimates of methane emissions from anthropogenic sources in the US. Research was also conducted to identify replacements for ozone depleting substances and to investigate more environmentally beneficial techniques to use waste methane from landfills and digesters via fuel cell conversion to electricity. As these activities were nearing completion and budgets were decreasing, ORD reevaluated the focus of the risk management component of the program and decided to reduce research on alternatives for ozone depleting substances and methane emissions and to emphasize investigations of new systems and fuels (biomass) that can be used to replace fossil fuel use in the industrial and transportation sectors. More recently, the risk management program has identified as priorities adaptation research and improvement of models used to compare mitigation technologies. The former has been included because of IPCC findings that clearly indicate some additional warming will occur regardless of actions taken to reduce emissions and the latter because there is a need to upgrade and refine the data used by researchers and policymakers to compare alternative GHG emission reduction technologies. ORD is particularly interested in using the results of these comparisons to identify where future investments in GHG technology research, development, and demonstration (RD&D) should be focused to have the greatest impact.

In 1995, EPA initiated the Science to Achieve Results (STAR) extramural research program as a fundamental part of its research strategy. A direct outcome of the updated research strategy and workshop was the announcement by ORD's National Center for Environmental Research and Quality Assurance (NCERQA) of a Request for Applications (RFA) on Regional Hydrologic Vulnerability to Climate Change in February 1995 and the subsequent issuance of an RFA on Integrated Assessments in December 1995.

Based on this evolution and current USGCRP priorities, ORD's Research program will focus on ecological vulnerabilities of ecosystems to climate change, the implications for human health, and mitigation and adaptation approaches. In the context of national and international global change research, ORD's program focuses on the impacts of human activity on terrestrial (including associated aquatic and coastal systems) ecosystems and on GHG emissions. This is illustrated in Figure 1, which shows ORD's ecological research focus on the impacts of climate and land use change on terrestrial ecosystems, and our risk management focus on how human activities influence emissions of GHGs. The adaptation program focuses on how human activity should change in response to anticipated climate change. ORD's program fills an important niche in the international research program in that it focuses on the interactions between biogeochemical cycles, the physical climate system and on interactions with human activity.

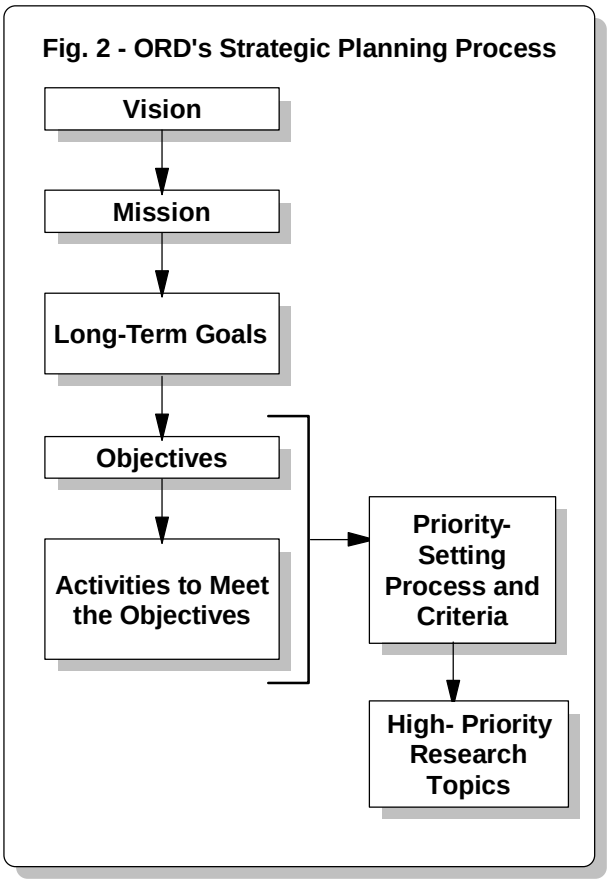
It is the unique mission of EPA to go beyond resource management assigned to other agencies like NOAA's National Marine Fisheries, USDA's Forest Service, DOI's Fish and Wildlife Service and Bureau of Land Management, among others, and to protect the whole of the environment, including accounting for the actions taken by other departments and agencies. While ORD's contribution is small in terms of relative resources, EPA's unique role in evaluating the impact of actions of resource



management agencies, as well as its direct responsibilities in Global Change, argues for a significant research program in the area.

3. RESEARCH PROGRAM

In the formulation of this strategy, critical gaps in scientific knowledge and the resulting scientific questions were considered in the context of their impact on EPA efforts to develop domestic and international climate change policies. EPA's needs include an improved scientific basis for understanding the implications of climate change on ecological systems in the context of other stressors and improved scientific and technical information that will facilitate identification and implementation of cost-effective risk management options.



Mission

The development of this strategy follows ORD's Strategic Planning Process, shown in Figure 2, with the development of a mission consistent with ORD's **Vision** of providing the scientific foundation to support EPA's mission. **In the context of Global Change, the mission of the ORD's research program is to improve the scientific basis for evaluating important ecological and human health impacts posed by climate change in the context of other stressors, and improve understanding of the best ways to manage the most significant of these impacts.**

Long-Term Goals and Objectives

The research strategy focuses on two fundamental, long-term goals:

- identification and evaluation of regional ecological vulnerabilities (including associated human health impacts) to temperature and hydrologic changes associated with predicted changes in climate, and

- identification and evaluation of adaptation strategies and cost-effective technologies to prevent or control GHG emissions.

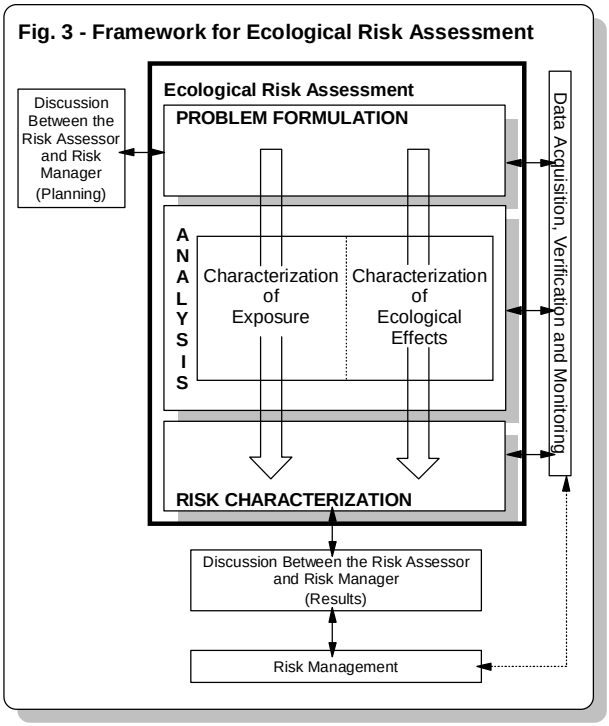
The objectives of the EPA Global Change research program are to address key scientific questions concerning:

- factors affecting ecological vulnerability to climate change;

- important human health risks associated with the ecological impacts of climate change;

- the feasibility, cost, and performance of emission reduction options; and
- selection of adaptation approaches to support local, state, and regional responses to climate change.

The Ecological Risk Assessment Process



In defining activities to meet the Long-Term Goals and Objectives, ORD's Global Change Research Strategy is developed using the Framework for Ecological Risk Assessment illustrated in Figure 3. Ecological Risk Assessment is shown as a three-phase process including problem formulation, analysis, and risk characterization. Important activities associated with ecological risk assessment include discussions between risk assessors and risk managers and data acquisition and monitoring. Ecological risk assessments frequently follow an iterative or tiered approach, with significant feedback between risk analysis, characterization, assessment, and management.

The emphasis on coordinating or integrating future research by different ORD Laboratories and Divisions for the purpose of conducting regional assessments has stimulated planning of research around programmatic areas that correspond to the steps in the Agency's ecological risk assessment framework: problem formulation, characterization of exposure and effects, risk characterization and risk management. ORD's National Health and Environmental Effects Research Laboratory (NHEERL) and National Exposure Research Laboratory (NERL) programs are primarily focused on the first two of these components, while the National Center for Environmental Assessment (NCEA) programs deal largely with the third. Information on GHG emission reduction technologies and adaptation approaches is performed by ORD's National Risk Management Research Laboratory (NRMRL). ORD research areas are summarized in Table 4 (page 26) and are discussed in the following sections.

Problem Formulation

In the Problem Formulation phase of the Ecological Risk Assessment process, consideration was given to the material reviewed in previous sections. The state of science as expressed in the 1995 IPCC Science Assessment was considered, along with the national priorities set by the USGCRP. We reviewed the evolution of ORD's research program in Global Change to identify key expertise and capabilities developed to date. We then applied ORD's Strategic Plan and developed Goals and Objectives for the ORD Global Change Research Program consistent with that strategy.

(1) *Addresses the Highest Risks to People and the Environment*. Global change is an area identified in the ORD Strategic Plan as an area appropriate for EPA research and is consistent with recommendations in the IPCC Assessments and the USGCRP.

(2) *Addresses Uncertainties in Important Health and Ecological Risk or Cost-effective Management and Adaptation Strategies.* The focus is on research that reduces the greatest uncertainties in the assessment and management of health and ecological risks from global change, and the viability of mitigation and adaptation options to reduce risks. The research currently being conducted by other organizations has been considered in setting priorities and allocating resources. ORD aims to fill critical gaps in data and knowledge, allowing for more efficient allocation and leveraging of resources at EPA.

(3) *Able to Make a Unique Contribution.* This criterion focuses on ensuring that EPA has access to the facilities and expertise to conduct or oversee the needed research. In-house expertise is necessary to oversee research, even if it is conducted by cooperative agreement or contract. Capabilities of the extramural scientific community are tapped through EPA's investigator-initiated, competitive, peer-reviewed STAR (Science to Achieve Results) grants program to complement the inhouse program.

(4) *Relevant to the Development of Policy.* Importance is placed on the expected utility of the research products for addressing both short- and long-term assessment and risk management issues. EPA's Office of Policy and Program Evaluation (OPPE) and Office of Air and Radiation (OAR) are the primary internal clients of this research. This research also supports the Office of Water (OW) and Office of Prevention Pesticides and Toxic Substances (OPPTS).

Table 2 - Criteria for Prioritizing Research

Several criteria, shown in Table 2, for setting priorities for ORD's Global Change Research Program were developed to help identify activities to meet the objectives. These criteria are consistent with ORD's Strategic Plan but are specific to the Global Change Research Program. The criteria lead to the following two areas as the strategic foci for the research program:

Ecological Vulnerabilities to Climate Change

ORD's first major focus is to provide a stronger scientific basis for understanding, predicting, and assessing the causes and impacts of changes in terrestrial, aquatic and coastal ecosystems resulting from human-induced and natural stressors. A fundamental inconsistency exists in efforts at detecting impacts of global change. The changes in climate and atmospheric chemistry of concern to scientists are probably measurable unambiguously only at global scales, while the impacts of global environmental change of concern to citizens and decision-makers are those that affect life at regional to local scales. Similarly, scientific interest resides at the regional level because this is the scale at which ecosystem responses take place. Yet, in any given region, specific environmental changes can be attributed to the wide variety of forces operating there; increasing resource extraction, declining soil fertility, urban-suburban growth, changing atmospheric pollutant loads, land use fragmentation of landscapes, and so on, in addition to the chronically changing seasonal temperature and precipitation patterns of interest here. The dilemma is how to tease out and evaluate regional impacts of global environmental change from other regional changes.

Selecting a regional scale of analysis is also valuable for at least two other reasons: (1) regional analyses may be more readily linked with policy development, particularly development of adaptation strategies; and (2) the ecological mechanisms causing an observed effect can be best identified on a regional scale. Scale, in fact, needs to be investigated. What is the appropriate scale to monitor, understand and assess ecosystem change (e.g., State-level, administrative/political units, or watershed of major drainages)? Do small-scale or regional-scale impacts "add-up" to national- or global-scale consequences? Will small-scale adaptations result in global consequences?

The effort to achieve this research goal requires a wide range of activities. For example, observations are needed to document changes in land cover, coastal alterations, changes in species home ranges, and other ecosystem level responses. Research is also needed to quantify process rates and provide information for predictions of ecological conditions based on these processes. Combined information on patterns of change and processes causing these changes is needed to provide the foundation for evaluating landscape, coastal margin, and ecological changes due to global forcings (e.g., greenhouse gases, climate) as well as due to local and regional influences (e.g., watershed alterations, chemical contamination). The influence of ecological and other adaptations must also be understood and evaluated to determine how adaptation will impact the environmental protection infrastructure already in place in the US and as a feedback loop for future assessments. Changes in emissions of greenhouse gases and implementation of emission reduction options (see below) will also be important for future ecological vulnerability assessments because they will be used to modify projections of future warming and thus will influence future exposure characterizations.

Risk Management Research

To effectively manage the potential effects of global change, the US and other nations will have to implement a variety of emission reduction and adaptation measures. Due to the uncertainties about the significance of ecological and human health impacts and the wide variety of emission sources, an array of adaptation and GHG emission reduction options will be needed if the international community decides to take action. An investment in research now will ensure there are a wide mix of options available in the next century. Research by government and the private sector will be needed to identify and develop management approaches and to compare their effectiveness. Where we can make a unique contribution, ORD will, in cooperation with industry and other government agencies, fill gaps in knowledge about the viability of promising options identified by the IPCC and EPA policy offices. Research to upgrade models now used to compare the cost and effectiveness of various GHG emission reduction options, to evaluate GHG reduction technologies for selected sources, and to assess adaptation options will be included in the ORD research agenda. Within each of these areas, ORD is only conducting a small subset of the research needed and recognizes that areas such as advances in solar, wind, and nuclear power and technologies that produce energy efficiency improvements for buildings and industrial processes are covered by other research programs within the federal government or the private sector.

Characterization of Exposure and Effects	
Ia	What are the regional hydrologic vulnerabilities to climate change?
Ib	How do climate-induced changes in temperature, moisture, and atmospheric composition affect biogeochemistry of regions or ecosystems, and how do these shifts in biogeochemistry feedback to climate?
Ic	How can one identify future ecological vulnerabilities on a range of spatial scales resulting from the joint effects of changes in climate, sea level, and other stressors such as pollutants and land use?
Id	How do climate-induced changes in biogeochemistry affect species distribution and diversity, productivity, sustainability, and integrity of terrestrial, freshwater and coastal ecosystems?
Ie	What are the indicators (sentinels) of climate change at population, community, and ecosystem levels of organization?
If	How are human and ecosystem exposure to UV-B radiation changing? What are the effects of these exposures?
Risk Characterization	
IIa	How may climate change stress ecosystems in the context of other stressors?
IIb	What are the vulnerabilities of natural systems and regional economies within the US to global change?
IIc	How will climate change affect human health directly and indirectly, via ecologically-mediated factors?
Risk Management	
IIIa	How can existing models that identify sector-specific GHG emission reduction options be improved to guide future investments in global change technologies and assist policymakers compare the viability of mitigation options?
IIIb	How can GHG emissions from fossil fuel combustion, waste disposal operations and industrial operations be cost-effectively prevented or controlled and how can the technologies chosen be optimized to simultaneously provide reductions of other harmful air pollutants?
IIIc	What ecological systems and components of the existing civil and environmental infrastructure are most likely to be impacted by global change and how can specific regions of the US adapt to the anticipated climate changes?

Table 3 - Key Questions for ORD's Global Change Research Program

Key Scientific Questions

Consideration of the two strategic foci lead to identification of key scientific questions that should be addressed by the research program activities. These questions are detailed in Table 3, and Table 5 summarizes the questions addressed by each research project area. The following section discusses the project areas developed to address these key questions, and how they relate to the criteria shown in Table 2.

Characterization of Exposure and Effects

Coastal Ecosystem Vulnerability

Coastal ecosystems may be substantially affected by anticipated global climate changes to sea level, weather and UV-B and these are critically important resources in sustaining coastal margin, marine, and terrestrial species and for human habitation and welfare (criterion 1). Uncertainty exists in identifying and characterizing the geographic and temporal nature of this vulnerability (criterion 2), and reducing this uncertainty will directly affect coastal zone policy development (criterion 4).

In considering future regional vulnerabilities for US coastal ecosystems, climate change impacts will be considered in the context of other future risks to coastal ecosystems. Long-term data sets and trend summaries will be collected from various US Government agencies, state and local sources and used to characterize environmental changes in New England and the Mid-Atlantic affecting the water quality and ecology of watersheds and coastal ecosystems. In addition, new data will be collected to determine the extent to which rising sea level and other factors are already causing wetlands and other shores to erode, as well as the rates of shoreline armoring. Such collaboration will facilitate an analysis of spatial and temporal components of variance in human demographics and land-use, and relate these to variations in stream ecology, water quality, and pollutant transport (especially nitrogen) to coastal receiving waters, as well as habitats of terrestrial biota and watershed vulnerability to flooding. Retrospective analyses of relatively pristine watersheds will be conducted to identify the effects of climatic variability on stream flow and pollutant flux to the coast. A conceptual model based on these analyses will be developed to identify the principal drivers of change in selected watersheds and estuaries, and used to anticipate future changes in the region. Ecological risks associated with climate change can then be considered in the context of other future coastal zone pressures (e.g. eutrophication, hydrologic modification, coastal zone build-out, resource over-exploitation, habitat modification and loss). This geographic and temporal analysis will facilitate the identification of ecological vulnerabilities, "early warning indicators" and adaptive strategies for ecological risk avoidance in this region.

Environmental conditions that can be directly or indirectly affected by climate change (water temperature, nutrient enrichment, and salinity) will be examined as variables influencing the physical, chemical, and biological processes and community dynamics of algae and their resulting effects on fish, shellfish, and submerged aquatic vegetation (SAV). Long-term objectives include: (1) delineating eutrophication processes of near-coastal waters and resulting changes in community structure (water column plankton, benthos, fish, and coral reefs) and function (productivity, feeding dynamics, and biogeochemical and energy flows) and (2) developing community/ecosystem mechanistic mathematical models to assess effects of nutrient enrichment on selected system endpoints such as: (I) hypoxia/anoxia, (ii) loss of SAV habitat through processes dependent on nutrient enrichment, (iii) increases in nuisance and toxic phytoplankton blooms, (iv) qualitative and quantitative changes in linkages between primary and secondary productivity, and (v) relationships of trophic cascading and nutrient supplies as affected by eutrophication processes.

Factors Controlling Nutrient and Carbon Cycling:

The terrestrial biosphere is a dynamic system capable of directly affecting the global carbon budget. Large uncertainties exist in the terrestrial component of the global carbon budget, particularly with respect to how human activities alter the structure and function of terrestrial systems (criterion 2). Predictions of climate change are needed for policy development, and these predictions can be significantly improved by reducing the uncertainty in terrestrial-atmosphere carbon cycling (criterion 4). The following three project areas:

- Factors Controlling Nutrient and Carbon Cycling
- Terrestrial-Atmosphere Carbon Cycling, and
- Regional Climate Scenarios

address these criteria. In addition, in these areas, ORD has unique expertise and facilities that enable us to make a unique contribution to the science of global change (Criterion 3).

Research is increasing our understanding of the microbial/biological, chemical, and physical processes that control nutrient cycles, carbon storage and biosphere-atmosphere gas exchange. Studies in collaboration with other US and foreign institutions are conducted in fire-impacted boreal forest stands, along climate gradients in North American ecosystems, and in temperate and tropical regions of the Northern Hemisphere that are experiencing intense land use change. Specific projects deal with soil organic matter cycling using stable carbon isotope ratios and microbial lipid compositions, and interactions of climate change, solar radiation and nitrogen cycling in the coastal zone of the Southeastern US

Terrestrial-Atmosphere Carbon Cycling:

Research will address the needs to: (1) improve scientific understanding of the terrestrial carbon budget, including magnitudes, precision, and location of terrestrial sources and sinks, (2) determine how these have changed over the past decades, and how they may change in the future; and (3) project how human activity on the land has the potential to alter (positive or negative) the terrestrial carbon budget. Several models for relating human land use and management under changing climate constraints to the global carbon budget will be developed, with resolution at a sub-national scale (political units) and a capacity to cover regional, national, and global scales.

Regional Climate Scenarios

To understand the interrelationships between the terrestrial biosphere and other components of the earth system, a fully coupled earth system model (GENESIS) has been developed. GENESIS goes beyond existing general circulation models by including the simultaneous prediction of future atmospheric greenhouse gas concentrations and the accompanying climatic changes. Ongoing research is focused on coupling a detailed soils biogeochemistry model and a dynamic vegetation model to the other components of the full earth system model. GENESIS is being used to produce regional climate scenarios to provide credible projections for 10-50 years, and will be used by other ORD researchers to project regional impacts of climate change on terrestrial, freshwater, and marine ecosystems.

Characterization of landscape-level stressors and exposures at watershed scales

Research to characterize stressors and exposures is key in understanding the vulnerability of watersheds to significant impairment of ecological processes valued by society (e.g., clean water, productive forests, systems resilient to anthropogenic and natural disturbance) (criterion 2). The distribution and pattern of ecological resources and humans in watersheds influence ecological and hydrological processes that, in turn, affect sustainability of environmental attributes. Changes in landscape pattern can significantly influence the response of a watershed to climate change. Certain landscape configurations make watersheds more vulnerable to large-scale disturbance from climate change than others. Advances in remote sensing and Geographic Information Systems (GIS) permit analysis of landscape patterns over scales ranging from a few trees to whole continents. In particular, the completion of the North American Landscape Characterization (NALC) database of LANDSAT triplicates from the 70s, 80s, and 90s provides the opportunity to make a unique contribution to global change research (criterion 3). This research will develop remote sensing and GIS analysis techniques that analyze status and trends in landscape composition and pattern (landscape indicators) at multiple scales. The resultant links between landscape characteristics and vulnerability may be useful in identifying and formulating management options to reduce vulnerability to climate change. (criterion 4). The research will be conducted in the MidAtlantic Region but will be widely applicable.

Integrative Effects and Predictive Models

Ecological impacts from climate change are anticipated to occur at many scales (e.g., rhizosphere to forest-level to regional and, ultimately, global scales) and reflect complex interactions between the terrestrial biosphere and atmosphere. Substantial uncertainties affect estimation of the terrestrial effects of climate change, particularly as these effects relate to changes in multiple stressors such as changes in water cycle, temperature, CO_2 levels and tropospheric ozone (criterion 2). ORD is uniquely capable of conducting research to address the uncertainties in climate change effects on terrestrial ecosystems ranging in scale from microcosm to mesocosm, and extrapolation to forest stands (criterion 3). Reducing uncertainty in understanding how climate change impacts the goods and services humans value from terrestrial ecosystems, particularly with respect to multiple stressors, is critically important to estimating the economic and ecological impacts of climate change which in turn directly affects development of policy options to reduce these impacts (criterion 4).

The development and use of predictive models will also be an important aspect of assessing potential ecological effects. One such effort will adapt general ecosystem models and forest stand models to the forests of the Pacific NW. Modeling links between plant, soil, and climate processes have proven useful in evaluating ecosystem sensitivities and assessing vulnerabilities to climate stressors in a wide variety of biomes throughout the world. These models will also have broad applicability for determining the effects of many other stressors in PNW forests. Usually, understanding the way in which stressors act is necessary for successfully modeling their effects. Therefore, multi-stressor (e.g., CO_2, temperature and ozone) experiments will be carried out to measure the above and below ground responses of Douglas fir seedlings. These data will be used in estimating intermediate to longer-term effects of climate change stressors on ecosystem processes, and in calculating carbon, nitrogen, and water budgets of major terrestrial ecosystems.

Watershed Process Modeling

The potential impacts of climate change on freshwater ecosystems include changes in watershed processes and conditions leading to adverse effects on important species, such as fish. How watersheds respond to climate change, and how these changes results in adverse effects on important species (such as shifts in distribution) and ecosystems, remain uncertain (criterion 2). Research to develop, evaluate and integrate watershed models is needed to provide policy makers with tools for evaluating the freshwater ecology component in climate change impact assessments (criterion 4).

Initial development of models for simulating the effects of climate change on watershed processes controlling runoff and water quality will be completed through interagency research on the Little Washita River in Oklahoma and the Columbia River Basin. The model(s) will then be applied to two or more ecologically different watersheds to demonstrate its adaptability and to further its development. At the same time, initial steps will be taken to integrate the model(s) with those projecting terrestrial and atmospheric effects. Continuation of ongoing field and laboratory studies will provide information on the tolerance of fish and other aquatic organisms (macro invertebrates) to water quality conditions (temperature, flow, dissolved oxygen, nutrients, suspended solids) likely to result from watershed-level effects of climate change. This information will be used with predictive runoff models to assess the impact of altered climate on aquatic organisms. The results of this research will also provide information useful in conducting ecological risk assessments for stressors affecting aquatic ecosystems as the result of a wide range of existing human activities.

UV-B Research

Increased UV-B radiation flux at the earth's surface, which is associated with depletion of stratospheric ozone, may have very significant human health and ecological impacts, but the extent of these impacts is highly uncertain (criterion 2). Critical human health effects are known to result from UV-B exposure including skin cancer and cataracts, for which risks have been quantitatively characterized, and immune suppression, for which risks have not been characterized. The impact of immune suppression from increased UV-B exposure on vaccine effectiveness and incidence of infectious disease is uncertain.

Ecological impacts of UV-B exposure are also uncertain. UV-B radiation has been found to interact synergistically with polycylic aromatic hydrocarbons (PAHs). The resulting toxicity to aquatic life is a function of the intensity and duration of UV-B radiation and the tissue concentration of PAHs. This interaction has been demonstrated in laboratory tests with a number of species and combinations of PAHs. Because PAHs are nearly ubiquitous, there is a concern that the ecological impact of these compounds may be underestimated. Our research program is investigating the combination of these two stressors under environmentally realistic situations. The goal is to attempt to estimate the potential additional environmental risk over that predicted based on the individual risks of either PAHs and UV-B alone.

Some of these uncertainties can be relieved by coupling health and ecological studies with EPA's unique capabilities in monitoring ambient UV-B in different settings (i.e., urban and rural locations) as well as in the use of personal dosimeters to monitor individual exposures (criterion 3). Reducing uncertainty regarding exposures and effects of UV-B (especially interactions with other stressors) directly affects decisions on accelerating or modifying US actions regarding global change (criterion 4).

ORD's research in UV-B will enhance the monitoring of UV-B radiation and the evaluation of the biological effects of UV-B. The enhancement of UV-B radiation monitoring will leverage the integrated long-term monitoring network being developed in conjunction with the Committee on Environment and Natural Resources (CENR). In addition, monitoring data will be collected from other urban and rural sites strategically selected to support the determination of UV-B exposures to humans and ecosystems. These data will be coupled with studies of the effects of UV-B radiation on biological systems including potentially sensitive species. Through this research the health and ecologic consequences of UV-B exposure can be linked to exposure to provide a more quantitative assessment of risks. Thus, this research will cut across the health and ecological arenas and will investigate relationships between the effects of UV-B exposure seen in the environment and humans. In addition, linkages will be developed between characterization of exposures, the effects of these exposures, and the change in UV-B exposure in response to control strategies. A feedback loop using a systems approach that integrates urban and rural UV-B monitoring with estimates of the effects of UV-B exposures will result in the identification and evaluation of efficacy of risk management options.

Indicators Research

Because ecosystems are dynamic and undergo change as a function of time and in response to stressors, it is difficult to specifically identify whether and how climate change is affecting ecosystems. Development of indicators of climate change, therefore, is a very significant research need that EPA is uniquely positioned to address given ORD's research capabilities in indicator development and analysis (criteria 2, 3). With development of sensitive and accurate indicators of ecological impacts in response to climate change, difficult policy decisions regarding US actions to address factors affecting climate change would have an improved scientific basis (criterion 4).

EPA's research in ecological indicators will expand the development and integrated evaluation of indicators of global climate change. Because indicators of global change may be subtle, research will pursue a number of opportunities to identify indicators from a diversity of ecosystems ranging from mountaintop flora to coastal estuaries. Indicators research will include freshwater watershed indicators, such as degree of shading or watershed retention time; terrestrial indicators of forest composition and processes in response to multiple stressors; and estuarine indicators such as changes in community trophic levels (interdependent nutrient cycles, such as between plants, animals and microorganisms of decay) resulting from changes in temperature, depth or modification of habitats. In that indicators effectively must integrate environmental conditions and response, indicators research allows a systematic coupling of exposure, effects and assessment activities. When coupled with adaptation and mitigation research, development of indicators of change and vulnerability to change will allow managers to classify watersheds and terrestrial systems according to risk and to focus development and evaluation of management practices to limit the risks.

Risk Characterization Research

EPA plays a unique role in the interagency global change research community, in that one of EPA's goals is to protect the environment for the benefit of the health of the human population, as well as that of global ecosystems. ORD's Global Change Research Program will focus on integrated assessments of the potential ecological risks of climate change on coastal, freshwater, and terrestrial

ecosystems from different regions through the US and extend the analysis to include the implications for human health (criterion 2). ORD will determine the specific cases for which ecological risk assessments will be feasible and most useful and focus its resources accordingly (criterion 4). ORD will assess the ecological vulnerabilities to climate change of selected ecosystems using the *Ecological Risk Assessment Guidelines.*

Hydrologic Vulnerabilities of Ecosystems

ORD is assessing how climate change affects the hydrologic vulnerabilities of watersheds through the STAR program. This program addresses the following areas: 1) translation of climatic information into water availability and other ecologic variables as required by water resource and natural resource modelers, 2) linkages with economic activities in various sectors competing for water resources, and associated feedbacks, and 3) linkages of water availability with natural resource response condition. Specific projects include: 1) alteration of water availability, water quality, and fish habitat in cold regions by climatic change, 2) improved methods for assessment of hydrologic vulnerability to climate change, 3) the influence of global climate change on mountain water resources, 4) vulnerability of water resources to global climatic change in the agricultural mid-west--ecological, economic, and regulatory aspects, 5) the vulnerability of low income households to the hydrologic effects of climate change, 6) regional streamflow sensitivity to climate change in an urbanizing environment, and 7) regional hydrologic vulnerability and adaptation to climate: an integrated assessment of the Susquehanna River Basin.

Direct and Indirect Effects of Climate on Human Health

ORD is doing a preliminary assessment of the potential human health impacts of ecological shifts due to climate change; both direct and indirect impacts will be considered. This project area addresses both risks to people (criterion 1) and uncertainties in important health and ecological risk estimates (criterion 2). The risk to human health from climate change is also highly relevant to the development of governmental policy in response to climate change (criterion 4).

The direct impacts, such as the increased frequency and intensity of heat waves, hurricanes, and storms, will have significant implications for environmental equity concerns -- in the US often the elderly, poor, infirm, or mentally ill people suffer the most from extreme weather events. ORD will work with representatives from the Centers for Disease Control (CDC) to analyze the morbidity and mortality following previous extreme weather events in the US such as the 1994 Chicago heat wave. The goal of this project will be to identify the patterns of human health impact of this type of extreme weather event, and develop a plan to reduce the risk of similar damage happening in the future.

The indirect impacts of climate change on human health are those that are mediated through ecological systems that may be impacted or altered with global change: namely, vector-borne diseases, such as encephalitis. Alterations in the patterns of temperature and precipitation will have impacts on the ecologies of both the vector host (mainly mosquitos), as well as the parasite or pathogen (mainly arboviruses in the case of encephalitis). These shifts in environmental conditions will then be linked with the ecology of the disease vectors and ultimately with disease spread and outbreaks. Through STAR, ORD will conduct ecologically-based risk assessments to characterize the risk of climate change to human health in the US. Case study analyses will be performed that

include climate change simulation downscaling, geographic information systems, and hydrologic and disease modeling. The case studies include water-borne crytosporidiosis and Cholera while the vector-borne disease case studies include Lyme and other tick-borne diseases, Dengue and Dengue Hemorrhagic Fever. ORD will also participate in various efforts of global disease monitoring and surveillance programs organized by groups such as the World Health Organization (WHO), National Institute of Health (NIH), and the CDC. ORD can contribute the ecological framework necessary for predicting climate change impacts on disease outbreaks.

Integrated Assessments

ORD's STAR program supports a number of integrated assessments that are quantifying the vulnerabilities and potential beneficial and adverse effects of natural systems and regional economies to climate change (criterion 2; criterion 4). These assessments include: 1) a national assessment of the impact of climate change on water resources, 2) a regional assessment of land use effects on structure and function in the central grasslands, 3) integrated assessment of the public health effects of climate change in the United States, 4) integrated assessment of economic adaptation strategies for climate change, impacts on Midwestern agriculture, and 5) sensitivity analysis of the effects of changes in mean and variability of climate on crop production and regional economics in the Southeastern United States.

Risk Management Research

Comparative Technology Assessments

The IPCC indicated in the 1995 Assessment that there is high value in developing better information about the costs and benefits of mitigation measures and how they might change in coming decades (criterion 2). Based on this identified need, ORD will invest in research to upgrade and refine the data used to produce comparisons of alternative GHG emission reduction technologies. For those technologies identified as the most promising based on these comparative technology assessments, ORD will identify priority research and development needs. This research area was chosen because ORD has identified gaps in knowledge where its experience evaluating the cost and performance of GHG reduction technologies, characterizing emissions, and developing emission projection tools could readily be applied (criterion 3). Research will be initiated to improve the emissions data for selected source categories where lack of data impedes the capability to understand how important the source will be in achieving reduction targets and to improve information on the cost and performance of emission reduction approaches for those GHG source categories such as waste management facilities (i.e. landfills, lagoons, digesters) where ORD has unique expertise. The result of the research will be to improve the information available to (1) define what prevention and control technologies need to be developed, refined, or implemented in order to achieve specific levels of emissions reductions, (2) perform tradeoffs between various options, and (3) determine if anticipated or claimed benefits are reasonable. Information generated from this research can also be used to evaluate how implementing specific GHG technologies will reduce other air pollutants of concern such as nitrogen oxides, sulfur oxides, volatile organic compounds, and particulates (criterion 4).

Evaluation of Specific Greenhouse Gas Reduction Technologies

The IPCC in its Working Group II report stated "accelerated development of technologies that will reduce greenhouse gas emissions and enhance greenhouse gas sinks - as well as understanding the barriers that inhibit their diffusion into the marketplace - requires intensified research and development by governments and the private sector." (criterion 2) Improved technologies are needed for many sources across economic sectors (i.e., energy supply, waste disposal, transportation).

The ORD research proposed is focused on a limited number of technologies where existing expertise can be readily applied and little or no other active research is underway in either the public or private sector (criterion 3). For example, the biomass research activities described below were chosen based on the more than twenty years of experience ORD has evaluating how to reduce emissions of environmental contaminants by modifying combustion systems and evaluating gasification processes. Similar rationale was used for selecting research on methane and replacements for HFC and HCFCs. ORD's knowledge of emissions from methane sources provides the background necessary to evaluate and recommend ways to optimize energy conversion systems which use waste methane and prior research performed on alternatives for ozone depleting substances places ORD in a unique position to conduct research on compounds that have a low total-equivalent-warming impact. All of these areas have been identified by the IPCC as promising options to reduce GHGs and as areas where RD&D is needed to accelerate commercial availability of technologies. EPA's policy offices have also expressed interest in each of these areas. (criterion 4)

Research will include studies to (1) investigate a novel process to produce methanol or hydrogen using a combination of biomass gasification and natural gas, (2) evaluate small systems for industrial and commercial applications that use biomass to generate power (DOE and TVA have large programs focused primarily on larger biomass systems), (3) optimize and demonstrate technologies that use readily available "waste" methane at lagoons and natural gas facilities, and (4) evaluate alternative compounds with low total-equivalent-warming impacts which can be used to replace HFCs and HCFCs used in a variety of refrigeration and space cooling systems (CFC replacements will be a major GHG source in the next century if new solutions are not found).

Adaptation to Climate Change

The IPCC 1995 Assessment expresses a strong need for research on the efficacy and cost-effectiveness of adaptation strategies. It appears inevitable that some additional warming will occur even if actions are initiated in the next few years to reduce emissions (criterion 1). As a result, adaptation strategies will be a critical component of an overall strategy to protect ecological systems and human health from the adverse impacts of global warming. This is a broad area where ORD has again narrowed its focus to those areas where it has unique capabilities to make a contribution. One priority of the ORD adaptation program will be to use case studies to evaluate the likely impact of climate change on environmental protection strategies now in place (e.g. drinking water treatment) in order to illustrate the needs and potential for adaptation approaches. Where necessary, field studies of the most promising approaches will be conducted.

Areas of initial focus will be to identify actions which can be taken at drinking water supply, treatment, and distribution systems to handle increases in water borne diseases; define the role constructed wetlands could play in mitigating adverse effects; and determine how tropospheric ozone control strategies will need to be adjusted due to global change. ORD's experience investigating solutions for these environmental problems provides the knowledge base necessary to identify viable adaptation options (criterion 3). Future research will investigate how to manage ecosystems so they can adapt to multiple stressors. Climate-stressed ecosystems of interest are 1) non-tidal wetlands, 2) watershed storm water systems, 3) riparian zones, and 4) coastal zones. The research approach will define ecosystems at risk, develop management options for a wide range of climate stressors as determined from the sensitivity functions, and develop cost data for the adaptation approaches and strategies identified. ORD's knowledge of technological solutions and restoration activities available to address these problems puts it in a unique position to evaluate what needs to be done to reduce the incremental impacts to these ecosystems caused by climate change (criterion 4).

4. FUTURE DIRECTIONS

The future direction of the Global Change Research Program is set by the Federal Budget process. The FY98 budget request has been submitted to Congress and is now being debated. This strategy is based on the FY98 President's Budget Request and initial planning for the Out-Years.

Fiscal Year 1998

For reference, the FY98 President's Budget Request for the ORD Global Change Research Program is reproduced in Appendix A. In FY98, The Agency has requested an increase in funds to support expansion of the program in two areas: (1) UV-B and (2) the development of global indicators. While this investment represents a new orientation in the areas of ultraviolet and global indicators research, the base program represents effort formerly done within the Environmental Monitoring and Assessment Program (EMAP).

EPA's investment in UV-B will enhance research in the evaluation of the biological effects of UV-B. Funds will be used to maintain a UV-B monitoring network of seven sites located primarily in urban areas. Data collected via this network will be used to determine the occurrence and distribution of UV-B and to perform trends analyses. Another research focus in 1998 will be the investigation of UV-B effects on aquatic and terrestrial systems, including the biological effects of UV-B on sensitive biota.

EPA's investment in ecological indicators will expand the development and integrated evaluation of indicators of global climate change. While ecosystem indicators research will continue under the Ecosystems Protection program, this investment will combine and expand upon existing indicators research related to global stressors.

In 1998, EPA will redirect $786,800 and 5.4 total workyears from stratospheric ozone resources to global climate change to expand the risk management portion of the Global Change Research Program. This redirection will be used to study advanced technologies that will meet future national and international targets for greenhouse gas reductions.

Out-Year Emphasis

Initial planning is underway for FY99 and Out-Years, but results are not available at present. In fact, USGCRP and extramural review of this strategy will help determine these priorities. The project areas described in the previous section are listed in Table 4 and preliminary Out-Year directions are shown.

The areas expected to receive increased emphasis address national priorities for research in the area of indicators of change, including landscape-level response to stress, and for examination of coastal ecosystem vulnerability, an area where impacts of global change are expected to be particularly evident. It is also expected that these areas will be the subject of a request for extramural assistance through the STAR program.

Areas planned for continuing and redirected emphasis include some areas where increased internal emphasis (e.g., UVB research, human health, adaptation) is planned as well as areas such as biogeochemical cycling of carbon and nutrients, integrated effects and predictive models, and comparative technology assessments where ORD has unique expertise and facilities and plans to maintain capacity. Because it is a new area of ORD research, the adaptation program is also expected to issue a request for extramural assistance.

Areas of decreasing emphasis include research areas where shifts in resources are necessary to address emerging priorities (decreasing evaluations of specific greenhouse gas technologies to increase funding for adaptation and technology assessments) or projects that have received significant extramural assistance in previous years and are phasing out (Hydrologic Vulnerabilities, Integrated Assessments, Regional Climate Scenarios). Resources currently used in these areas will be moved to where continuing and increased emphasis is planned.

INCREASED EMPHASIS
Indicators Research [1]
Characterization of landscape-level stressors and exposures at watershed scales [1]
Coastal Ecosystem Vulnerability [1]
CONTINUING AND REDIRECTED EMPHASIS
UV-B Research (Exposure)
Direct and Indirect Effects of Climate on Human Health
Factors Controlling Nutrient and Carbon Cycling
UV-B Research (Effects)
Terrestrial-Atmosphere Carbon Cycling
Integrative Effects and Predictive Models
Adaptation to Climate Change [1]
Watershed Process Modeling
Comparative Technology Assessments
DECREASING EMPHASIS
Evaluation of Specific Greenhouse Gas Reduction Technologies
Hydrologic Vulnerabilities of Ecosystems
Integrated Assessments
Regional Climate Scenarios
[1] STAR Request for Assistance Planned

TABLE 4 - Out-Year Emphasis

5. SUMMARY

This document describes the ORD Global Change Research Strategy and presents a program for addressing key questions where ORD can have the greatest impact. The strategy is focused on the resolution of issues resulting from the recent IPCC report suggesting the potential for serious ecological and health effects due to global change, and on addressing priorities established in the overall Federal research program. This document describes the research areas and planned direction for the program over the next 3-5 years.

In Section 2, the current state of knowledge, as represented by the 1995 IPCC report, is summarized and current federal priorities are presented. The relationship of the USGCRP and ORD's program is presented and ORD's research activities in support of the federal program are discussed. How EPA's research program has evolved is discussed and the current and proposed program is presented in the context of the international research agenda.

Section 3 discusses the current program. The Mission, Long-Term Goals, and Objectives are presented in the context of ORD's strategic planning process and the Framework for Ecological Risk Assessment. Key scientific questions are developed and Research Areas addressing these questions are discussed in the context of evaluation criteria.

Section 4 discusses the FY98 research program emphasis and presents the proposed Out-Year direction for the program.

Table 5 summarizes the project areas, showing how they address USGCRP goals, and the key questions identified in the Problem Formulation phase of the Ecological Risk Assessment Process. Also shown are FY97 resources in each of the areas, and out-year directions are indicated. The supporting projects in the STAR program, both existing and planned, are also shown in Table 5.

TITLE	Key Question	USGCRP Goal or Theme	Lab.	FY97 Resources*		STAR Grants	Out-Year Emphasis from FY97
				FTE	Extramural $		
ECOSYSTEM VULNERABILITY							
Characterization of Exposure and Effects							
Coastal Ecosystem Vulnerability	Ia,b,c	Goal 4	NHEERL, NCERQA	6.5	153.0K	Planned (99)	↗
Factors Controlling Nutrient and Carbon Cycling	Ib	Goal 2	NERL	4.9	447.5K		→
Terrestrial-Atmosphere Carbon Cycling	Ib	Goal 2	NHEERL	2.0	172.0K		→
Regional Climate Scenarios	IIa	Goal 2	NERL	3.0	408.6K		↘
Characterization of ecosystem- level stressors and exposures at watershed scales	Id	Goal 4	NERL, NCERQA	2.1	178.9K	Planned (01)	↗
Integrative Effects and Predictive Models	Id	Goal 4	NHEERL	6.5	515.0K		→
Watershed Process Modeling:	Id	Goal 4	NHEERL	2.5	68.8K		→
UVB Radiation	Ie	Goal 3	NERL, NHEERL				↗
Indicators of Global Change	If	Goal 4	NERL, NHEERL, NCERQA			Planned (98)	↗
Risk Characterization Research							
Hydrologic Vulnerabilities of Ecosystems	IIa,b	Goal 4	NCEA, NCERQA	3.0 0.5	81.4K 2,200.0K	Existing	↘
Direct and Indirect Effects of Climate Change on Human Health	IIc	Theme 4	NCEA, NCERQA	0.4	1,000.0K	Existing	↗
Integrated Assessments.	IIa	Goal 4	NCEA, NCERQA	0.5	1,700.0K	Existing	↘
RISK MANAGEMENT							
Comparative Technology Assessment	IIIa	Goal 2 Theme 4	NRMRL	1.0	155.0K		↗
Evaluation of Specific Greenhouse Gas Reduction Technologies	IIIb	Goal 2 Theme 4	NRMRL	7.7	1079.2K		↘
Adaptation to Climate Change:	IIIc	Goal 4 Theme 4	NRMRL, NCERQA	1.0	0.0K	Planned (00)	↗

* - FY97 Extramural $ do not include Salary & Expense costs associated with FTEs.

Table 5 - Research Areas -- Key Questions, USGCRP Goals, and Resources

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APPENDIX A: 1998 President's Budget Request for Global Change Research

The Agency requests a total of $21,053,700 and 47.5 total workyears in 1998 for the Global Change program component. The request includes the operational support staff necessary to implement the research program. Staff support activities include program review, health and safety, resource planning and execution, administrative, financial contract and grant management, equipment and facilities maintenance and automated data processing (ADP).

Human activities are now formally recognized by the scientific community to have a significant influence on climate (IPCC Second Assessment Report, 1995). Effects of global change that are likely precursors of events to come are increasingly evident around the globe. Current data indicates that the atmospheric composition is changing more rapidly now than at any time on record. Precipitation has increased over land in high latitudes of the Northern Hemisphere, especially during the cold season. Global sea level has risen by between ten and 25 cm over the past 100 years and much of the rise may be related to the increase in global mean temperature. Thus, the scientific data strongly indicates that the current and future state of the global environment is inexorably linked to human activities.

The importance of these international issues was recognized by the United States through the passage of the Global Change Research Act in 1990 and the establishment of the U.S. Global Change Research Program (USGCRP). EPA's Global Change research program, and that of ten other Federal agencies, is planned and conducted under the auspices of the Committee on Environmental and Natural Resources (CENR) of the National Science and Technology Council (NSTC). EPA has the lead within the USGCRP for one of the USGCRP's highest priorities, ecosystem vulnerabilities. EPA's ecosystem vulnerabilities program will help to provide the scientific basis to assess, evaluate, and predict the ecological and socioeconomic sector consequences of global change, including the feedback these systems have on further climate change. Activities are also underway to support future risk management decisions in areas such as adaptation and source emissions reductions. EPA's program has four major components:

1) Research aimed at understanding the factors controlling sensitivity or vulnerability of ecosystems to global change (e.g., how might ecosystems respond to changes in ultraviolet radiation (UV-B) or how do stressors like temperature, carbon dioxide (CO_2) and ozone interact?), and the detection and quantification of changes within an ecosystem that indicate impacts of global change (indicators);

2) Methods and strategies for assessing vulnerability of ecosystems at regional scales;

3) Integrated assessments that provide the linkages of ecological assessments with other physical/natural, social, and economic systems; and

4) Research aimed at understanding the technical and economic viability of approaches which could be used to adapt to global change and minimize and cope with greenhouse gas emissions.

Major Activities

EPA plays a unique role in the interagency global change research community because a primary EPA mission is to protect the environment for the benefit of the health of the human population, as well as that of ecosystems. In 1998, EPA's Global Change research program will focus on integrated assessments of the potential ecological risks of climate change on coastal, freshwater, and terrestrial ecosystems from different regions throughout the U.S., and extend the analysis to include the implications for human health. In addition, EPA will consider future regional vulnerabilities for coastal ecosystems by developing a conceptual model to (1) identify the principal drivers of change in selected U.S. Atlantic watersheds and estuaries, and (2) evaluate ecological risks that may be associated with climate change in the context of other future coastal zone precursors (eutrophication, hydrologic disruption, resource exploitation, coastal zone build-out, etc.). Researchers will analyze the relatively pristine and more heavily impacted New England and Mid-Atlantic watersheds and incorporate this information into the conceptual model. The results of this research will be used to characterize environmental changes, not only in New England and the Mid-Atlantic, but in other areas across the Nation as well. Federal, state and local agencies will be able to use this model to determine future impacts affecting the water quality, and ecology of watersheds and coastal ecosystems.

Research will continue to focus on understanding the microbial, biological, chemical, and physical processes that control nutrient cycles, carbon storage, and biosphere-atmosphere gas exchange. Researchers will conduct studies in fire-impacted forests, along climate gradients in North American ecosystems, and in temperate and tropical regions of the Northern Hemisphere that are experiencing intense land use change. This research is critical because of the impact these processes have on the natural balance of the atmosphere and the subsequent contribution to global change, and the complex interactions of these processes in ecosystems. For example, impacts of global change are generally thought of in the context of "warming," but ecosystem-level impacts will more likely be mediated by changes in moisture (through changes in the distribution of rainfall) and associated microbial activity than changes in temperature. Other agencies (the National Oceanic and Atmospheric Administration and the National Aeronautics and Space Administration) conduct research on seasonal and interannual climate variation; EPA's research will extend this work to understand ecosystem impacts.

Changes in landscape pattern can significantly influence the response of a watershed to global climate change. Certain landscape configurations make watersheds more vulnerable to large-scale disturbance from climate change than others. Advances in remote-sensing and Geographic Information Systems (GIS) permit analysis of landscape patterns over scales ranging from counties to large regions. This research will develop remote sensing and GIS analysis techniques that analyze status and trends in landscape composition and pattern at multiple scales. The resultant links between landscape characteristics and vulnerability will be useful in identifying and formulating management options to reduce vulnerability to climate change.

In 1998, EPA will invest in UV-B radiation research to evaluate the biological effects of UV-B. Research will focus on problems such as the effects of UV-B radiation on sensitive sub-populations (e.g., amphibians). In addition, EPA will enhance research in the development of ecosystem indicators as sentinels of change. The focus will be on terrestrial, aquatic, and coastal

indicators that can detect and/or quantify the effects of climate change. Examples include migration of high altitude wildflowers, habitat (latitude and upstream/down-coast) change of fish distribution, or migration of boreal forest boundaries. The development of ecosystem indicators will assist EPA in detecting and quantifying the effects of numerous factors that impact ecosystems.

To understand the interrelationships between the terrestrial biosphere and other components of the Earth's system, EPA has developed a global circulation model incorporating the atmosphere, ocean and terrestrial biosphere. This model goes beyond existing general circulation models and simultaneously predicts future atmospheric greenhouse gas concentrations and the accompanying climatic changes. The model will be used to produce credible climate scenarios and as a basis for landscape and ecological modeling to project the longer term outcomes of current environmental management decisions.

The continual development and use of predictive models will also be an important aspect of assessing potential ecological effects. Modeling links between plant, soil, and climate processes have proven useful in evaluating ecosystem sensitivities and assessing vulnerabilities to climate stressors in a wide variety of biomes throughout the world. Understanding the way in which stressors act is necessary for successfully modeling their effects. Therefore, multi-stressor (e.g., CO_2, temperature and ozone) experiments will be carried out and modeled to evaluate key responses in important forest species. EPA will use the data collected to estimate intermediate to longer-term effects of climate change stressors on ecosystem processes, and in calculating carbon, nitrogen, and water budgets of major terrestrial ecosystems.

A model for simulating the effects of climate change on watershed processes controlling runoff and water quality will be completed through interagency research. The model will then be applied to two or more ecologically different watersheds in the Great Lakes region to demonstrate its adaptability and to further its development. At the same time, EPA will begin to integrate this model with those projecting terrestrial and atmospheric effects.

EPA's risk assessments under Global Change will continue to focus on two areas: (1) ecological impacts at the regional level and (2) health effects through potential changes in disease vectors. This research effort will improve our understanding of the ecological impacts of climate change in particular regions and the subsequent impacts on human health that may be mediated through these ecological systems. Such research efforts are intended to quantify the vulnerabilities to and potential effects of global climate change on human health, natural resources and regional economies.

Global change risk management research will include studies to (1) assess the viability of adaptation strategies, (2) compare the cost, technical feasibility, and environmental benefits of potential greenhouse gas emission reduction technologies, and (3) develop and evaluate specific low-cost greenhouse gas emission reduction technologies where EPA's unique technical expertise and facilities can accelerate their commercial use. In the adaptation area, feasibility studies will be initiated to identify approaches which could be used to reduce or eliminate the impact of global change and to evaluate how global change will impact strategies now in place to protect public health and the environment from other pollutants. The research to compare mitigation technologies will include evaluation and development, where necessary, of greenhouse gas emission projection and technology

models in order to improve U.S. and international capabilities to quantitatively compare a variety of options to reduce source emissions within and across economic sectors. The completed analyses will identify what future technological advances are necessary to reduce emissions cost-effectively, and thereby can be used to help establish future research priorities. EPA's unique expertise and existing facilities will be used to study low-cost options to replace (1) fossil fuels burned in small combustion systems and engines and (2) synthetic compounds which are likely to contribute to future global change.

Explanation of Change: -0.6 FTE + $6,915.1K

EPA will invest $7,242,200 in two areas: (1) UV-B, and (2)the development of global indicators. While this investment represents a new orientation in the areas of ultraviolet and global indicators research, the base program represents effort formerly done within the Environmental Monitoring and Assessment Program (EMAP) under the Ecosystems Protection program component. Thus, research pertaining to global indicators and UV-B has been moved from the Ecosystems Protection program component to the Global Change program component.

EPA's investment in UV-B will enhance research in the evaluation of the biological effects of UV-B. Funds will be used to maintain a UV-B monitoring network of seven sites located primarily in urban areas. Data collected via this network will be used to determine the occurrence and distribution of UV-B and to perform trends analyses. A new research focus in 1998 will be the investigation of UV-B effects on aquatic and terrestrial systems, including the biological effects of UV-B on sensitive biota (e.g., amphibians).

EPA's investment in ecological indicators will expand the development and integrated evaluation of indicators of global climate change. While ecosystem indicators research will continue under the Ecosystems Protection program component, this investment will combine and expand upon existing indicators research related to global stressors. Because indicators of global change may be subtle, research will pursue a number of opportunities to identify indicators from a diversity of ecosystems ranging from mountaintop flora to coastal estuaries. The indicators research will include freshwater watershed indicators, such as, (1) degree of shading or watershed retention time; (2) terrestrial indicators of forest integrity and sustainability in response to multiple stressors; and (3) estuarine indicators, such as changes in community trophic levels (e.g., interdependent nutrient cycles between plants, animals and microorganisms of decay) resulting from changes in temperature, depth or modification of habitats. In that indicators effectively must integrate the environmental conditions and response, indicators research allows a systematic coupling of exposure, effects and assessment activities. When coupled with adaptation and mitigation research, development of indicators of change and vulnerability to change will allow managers to classify watersheds and terrestrial systems according to risk and to focus development and evaluation of management practices to limit the risks.

In 1998, EPA will redirect $786,800 and 5.4 total workyears from stratospheric ozone resources to global climate change to expand the risk management portion of the Global Change Research Program. This redirection will be used to study advanced technologies that will meet future national and international targets for greenhouse gas reductions. Research efforts will focus on determining which technological advances would have the greatest incremental impact on greenhouse

gas emissions and will leverage funding available in other Federal agencies and industry to catalyze the development and demonstration of the most promising no- or low-global warming technologies.

EPA will disinvest $458,700 total from research investigating alternatives for ozone depleting substances (ODS). ORD has been working for the past seven years to identify chemical and non-chemical substitutes for ODS used in a variety of end-use applications. Most of the applications which used chlorofluorocarbons (CFCs) have switched, or are in the process of, switching to a permanent or interim replacement. While the entire problem is not solved (i.e., environmentally acceptable solutions are not available for all applications which use ODS), the research program is considered mature in relation to other EPA research areas where there are greater uncertainties.

1997 Program

The Agency's budget is a total of $14,138,600 and 48.1 total workyears within the Global Change program. The request includes the operational support staff necessary to implement the research program. Staff support activities include program review, health and safety, resource planning and execution, administrative, financial contract and grant management, equipment and facilities maintenance and ADP.

The 1997 Global Change research program will pertain to global climate change and stratospheric ozone depletion and focus on research prioritized according to ORD's risk-based process. The global climate change research will focus on regional vulnerabilities, integrative effects and predictive models, and options to reduce greenhouse gas emissions. Regional vulnerabilities will focus on ecological vulnerabilities to climate change and related impacts, such as the spread of water-borne diseases from changing climate patterns. Successful implementation of this research area will enhance EPA's ability to conduct Regional and state level vulnerability assessments and national level integrated assessments, allowing EPA to develop realistic bounds on the nature and magnitude of the vulnerabilities identified, and to assess the cost of mitigation and adaptation strategies. Integrative effects work will include evaluation of the effects of temperature and increased CO_2 on above and below-ground Douglas Fir systems. A predictive model is under development to estimate the changes of carbon between the biosphere and atmosphere caused by changes in the cover, use and management of land due to human activities. Long-term research will focus on Regional integrated assessments. Greenhouse gas emission reduction research will demonstrate the technical, environmental, and economic feasibility of replacing fossil fuels used in small combustion systems and engines. EPA will also do process and modeling research to study the coupling of the terrestrial biosphere to global change predictive models.

Stratospheric ozone depletion research will focus on the completion of property evaluations of synthetic chemicals that could be used as ODS replacements with increasing emphasis on alternatives for current ODS replacements having high global warming potentials.